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Near-Wall Velocity Field Measurements of a Very Low Momentum Flux Transverse Jet

50th AIAA/ASME/SAE/ASEE Joint Propulsion Conference

Cleveland, OH

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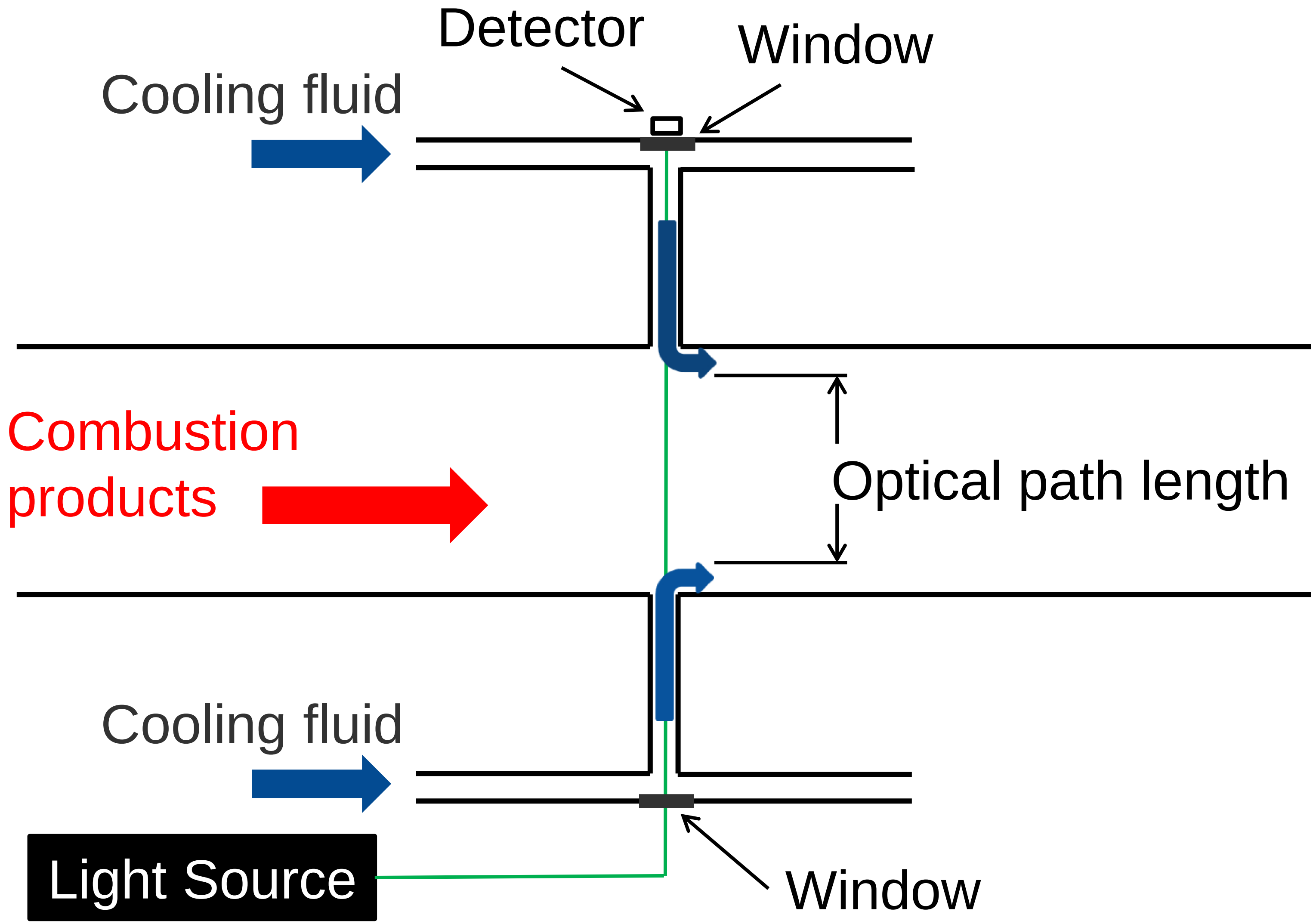
David Forliti, Sierra Lobo, Inc.
Kayla Kuzmich, AFRL/RQRC
Edward Coy, AFRL/RQRC

Integrity ★ Service ★ Excellence

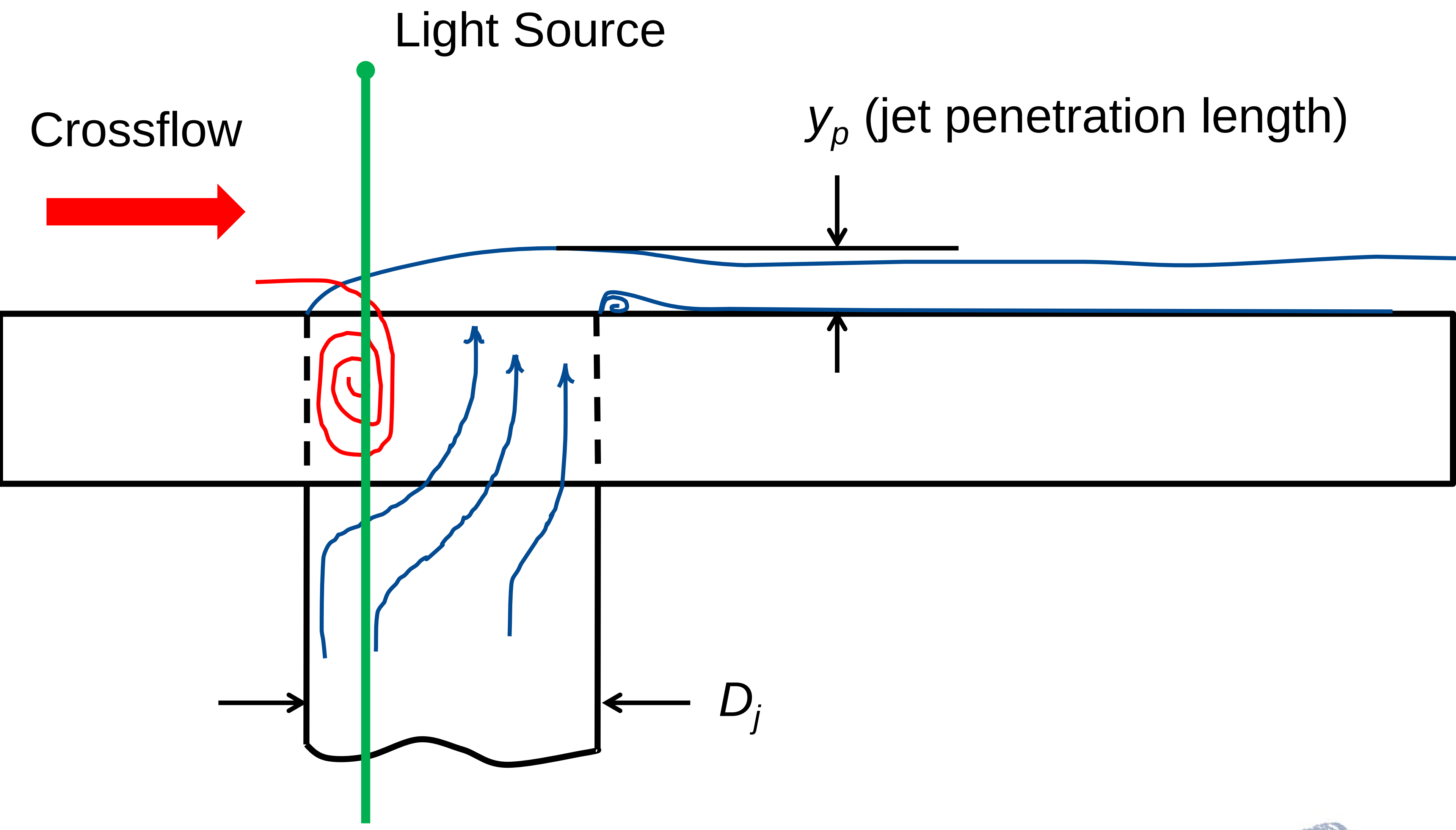
Outline

- Research Motivation
- Experimental Setup
- Results
- Conclusion

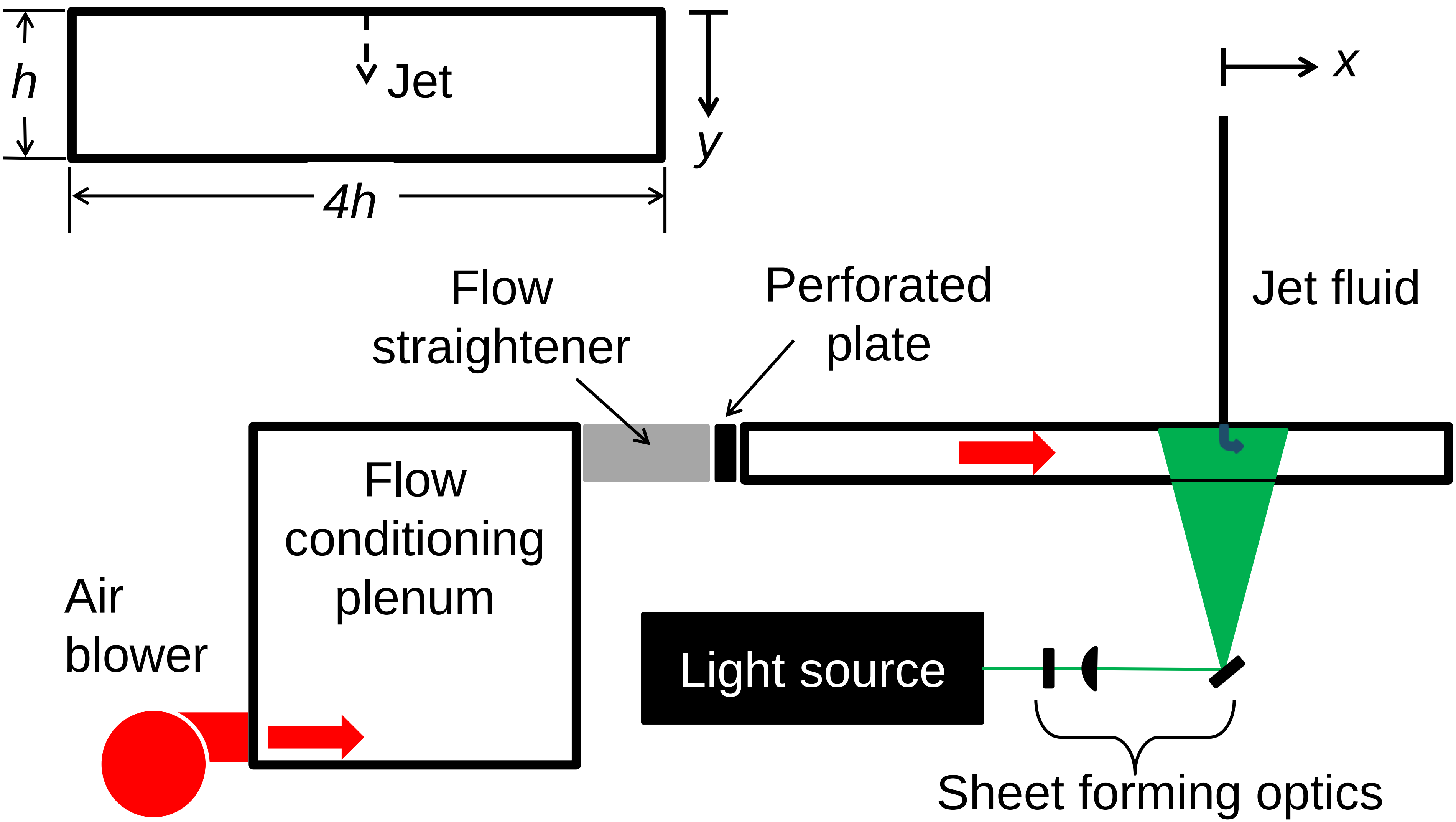
Optical Diagnostics



Jet and Crossflow Interaction

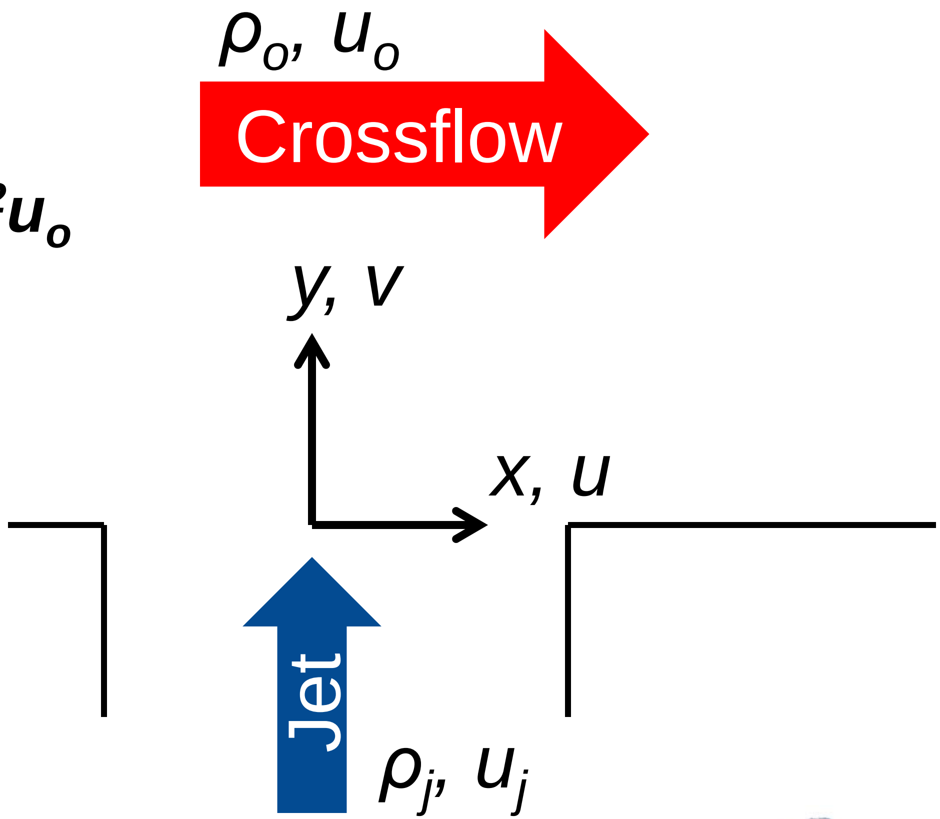


Experimental Facility

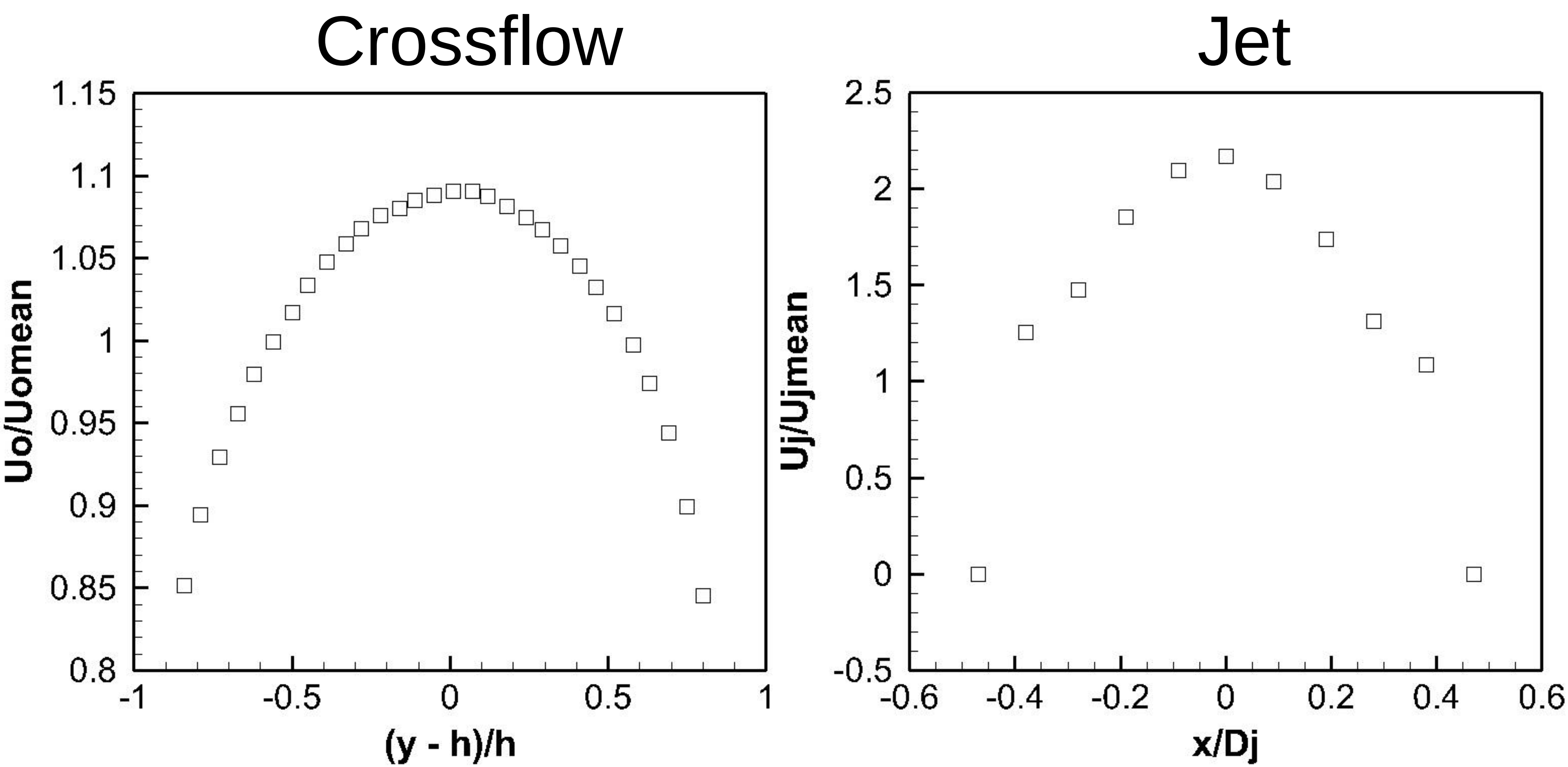


Important Parameters

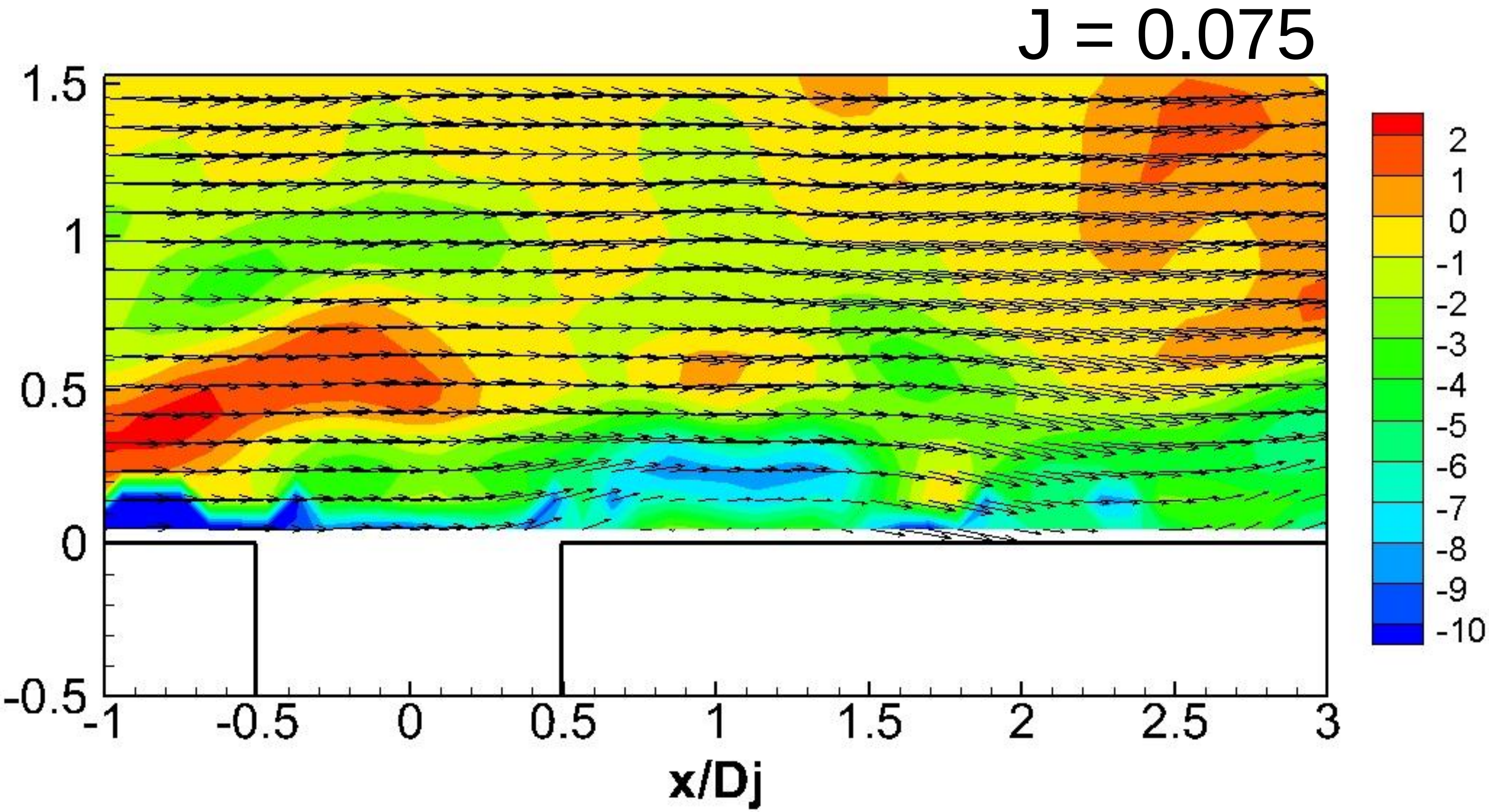
- **Momentum flux ratio**
  - $J = \rho_j u_j^2 / \rho_o u_o^2$
- **Blowing ratio**
  - $M = J^{1/2} = \rho_j^{1/2} u_j / \rho_o^{1/2} u_o$



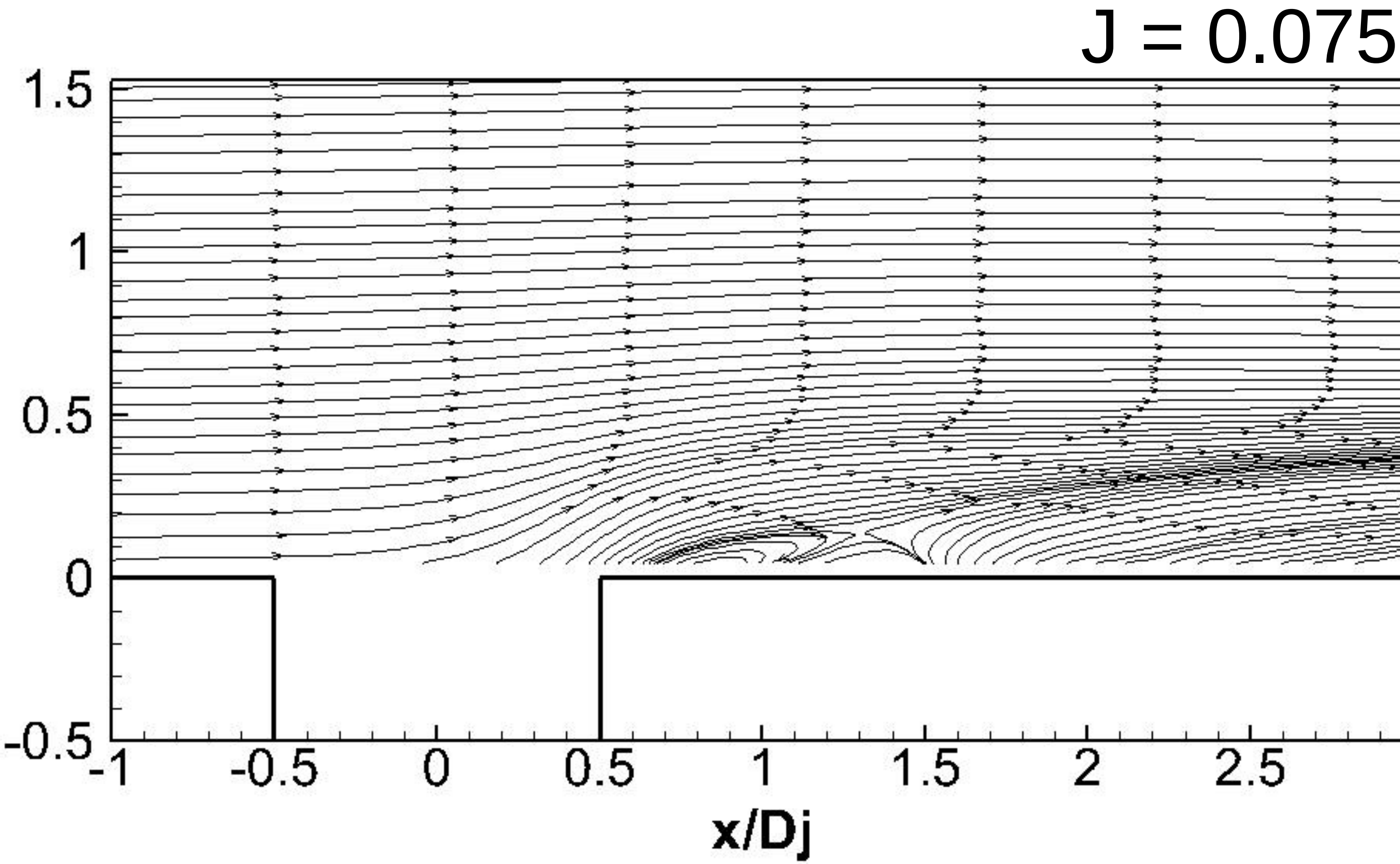
Initial Conditions



Instantaneous Velocity Field

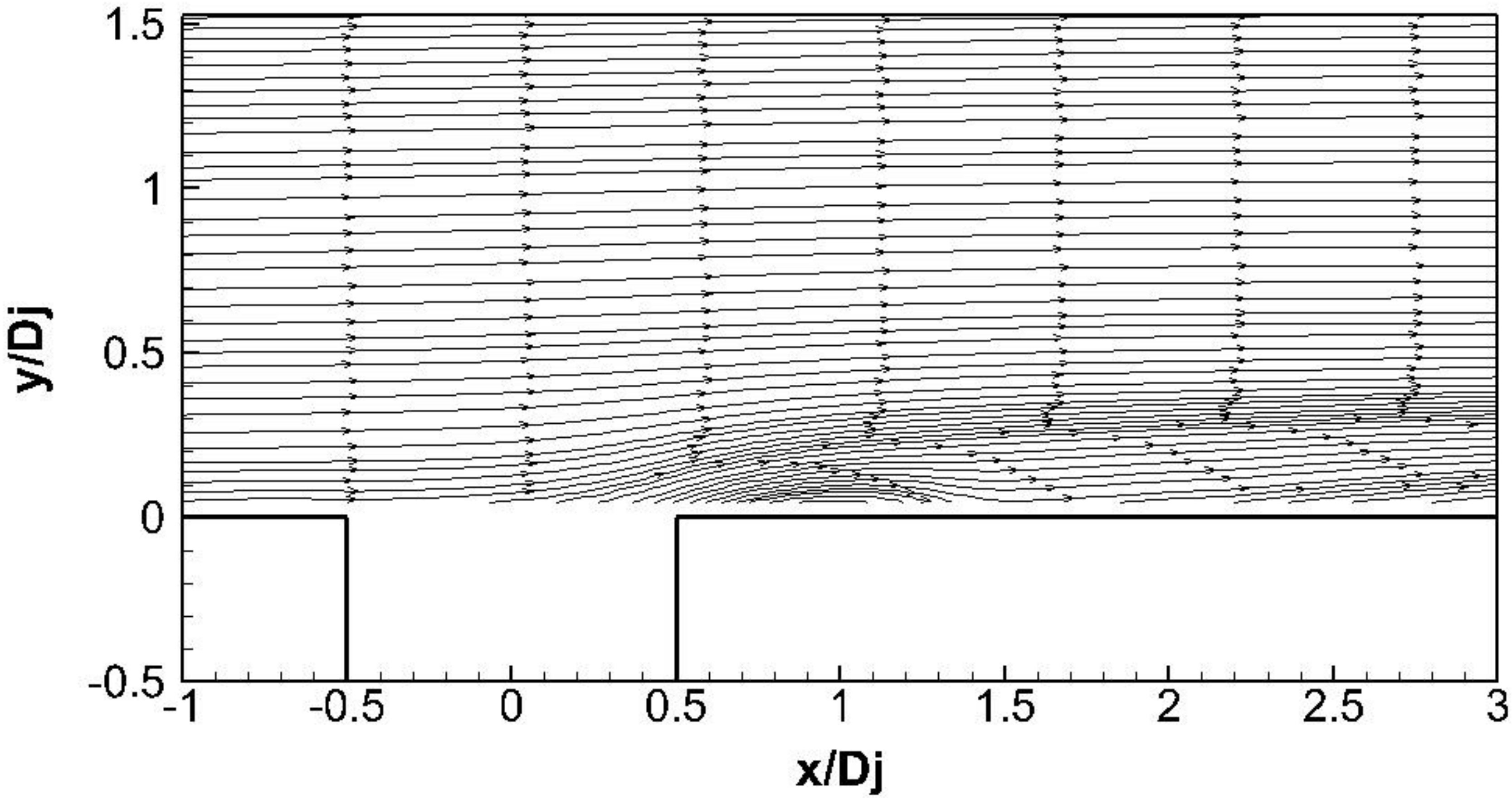


Mean Velocity Field – Streamlines

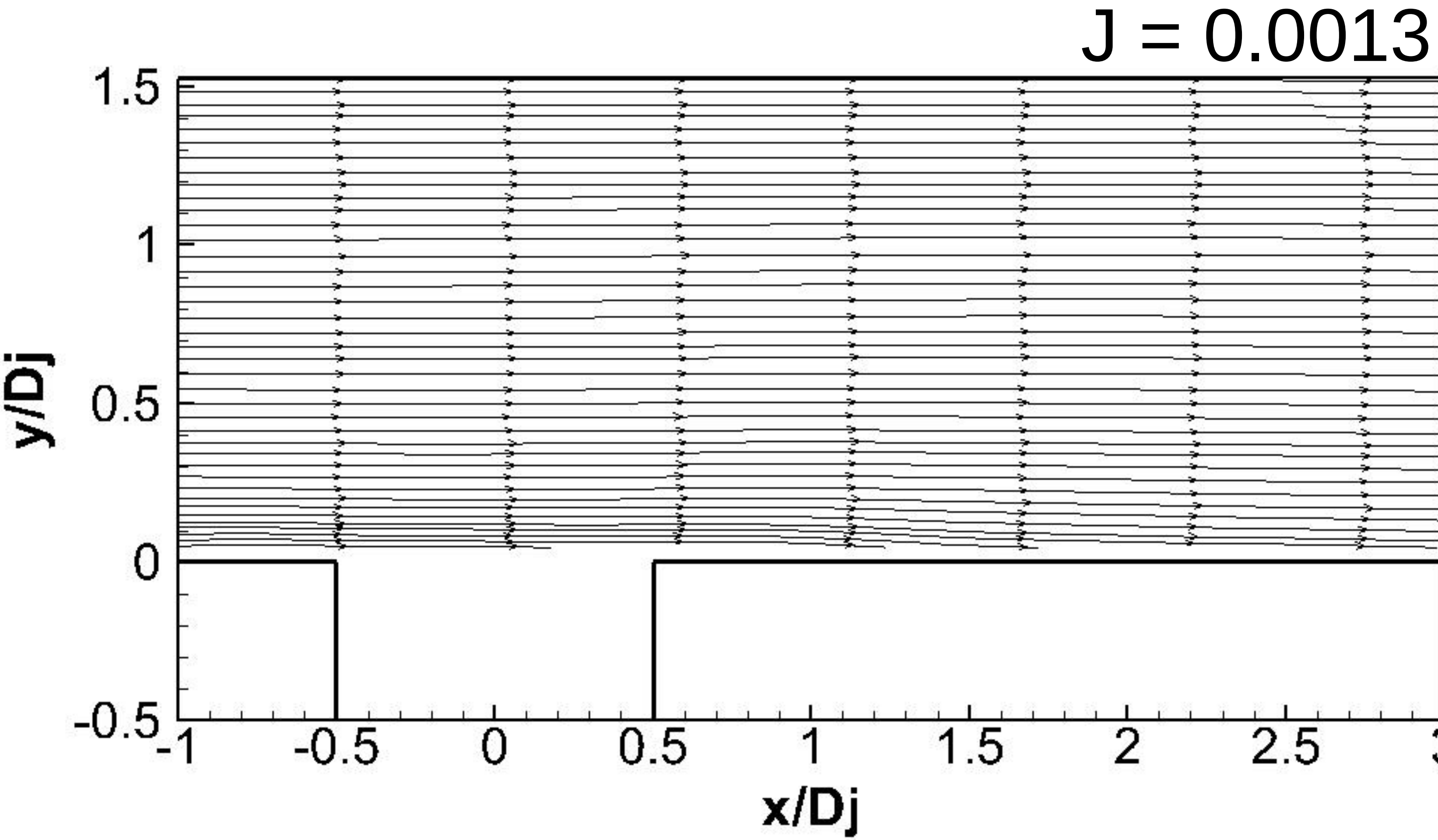


Mean Velocity Field – Streamlines

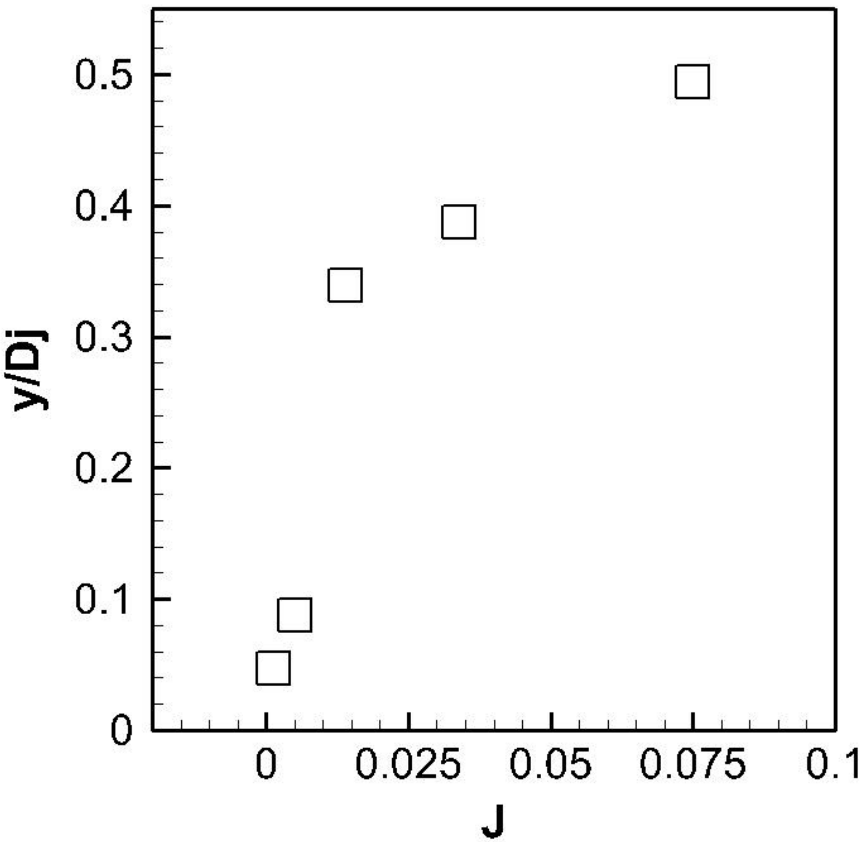
J = 0.014

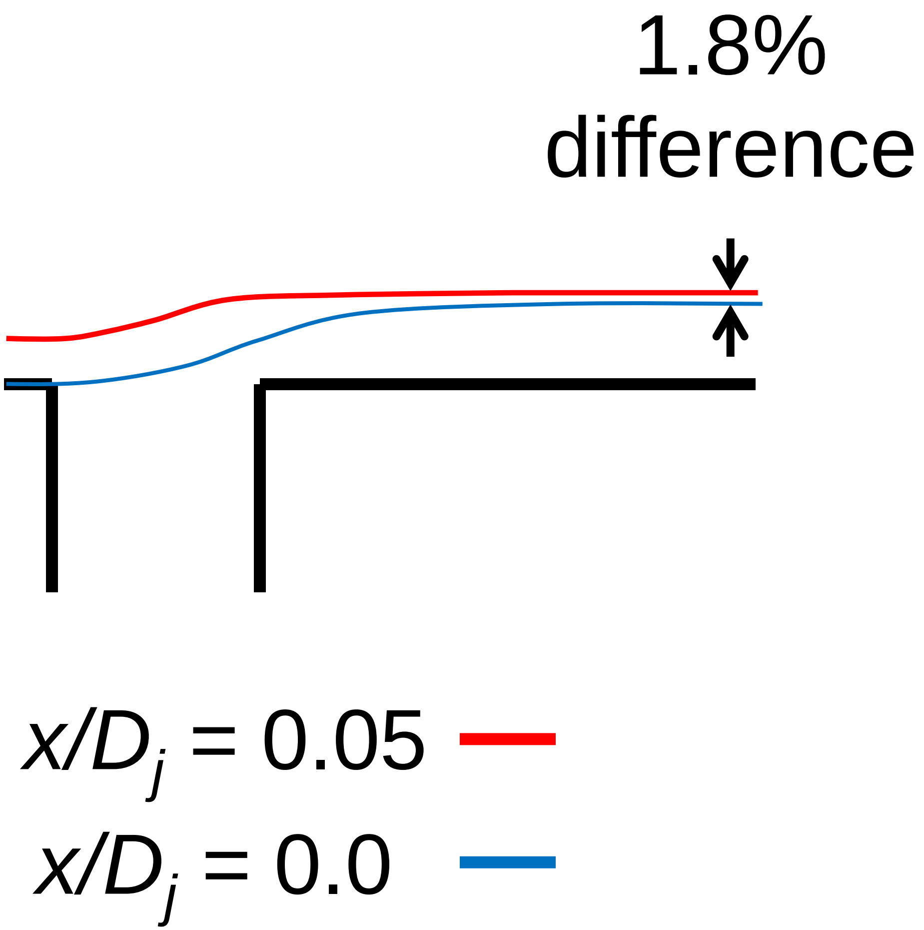


Mean Velocity Field – Streamlines

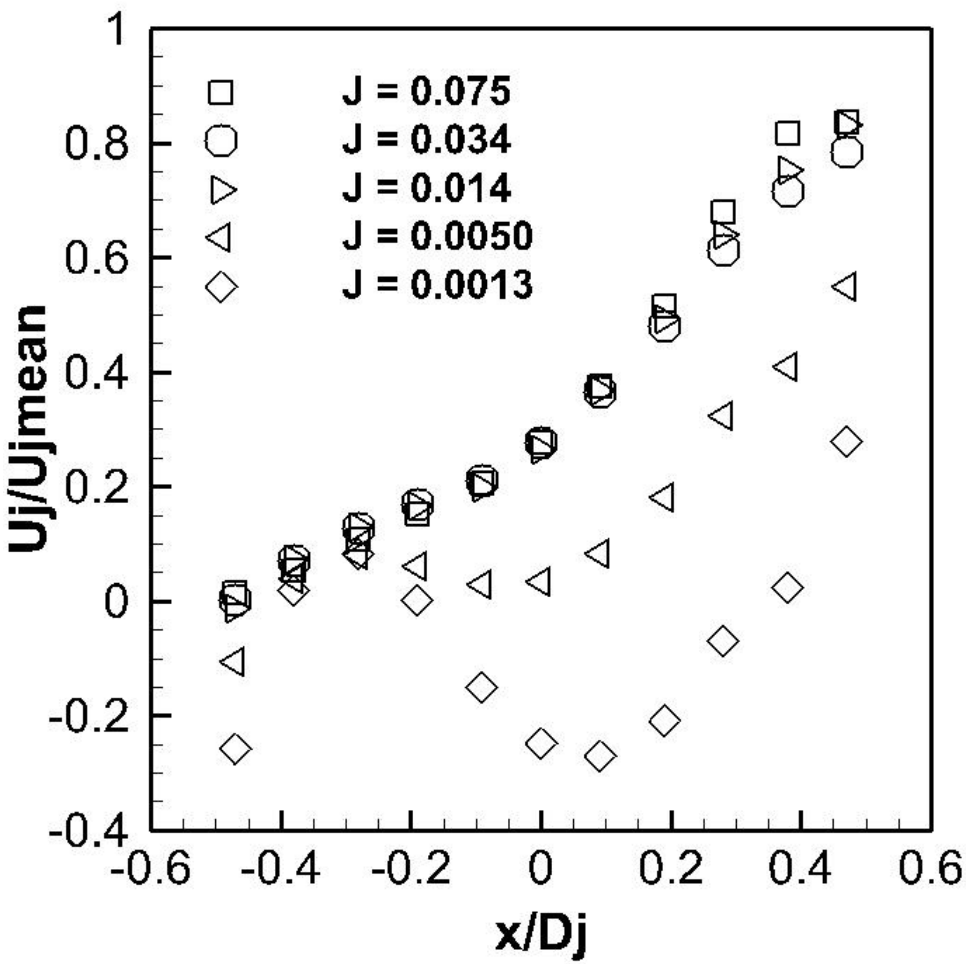


Maximum Jet Penetration

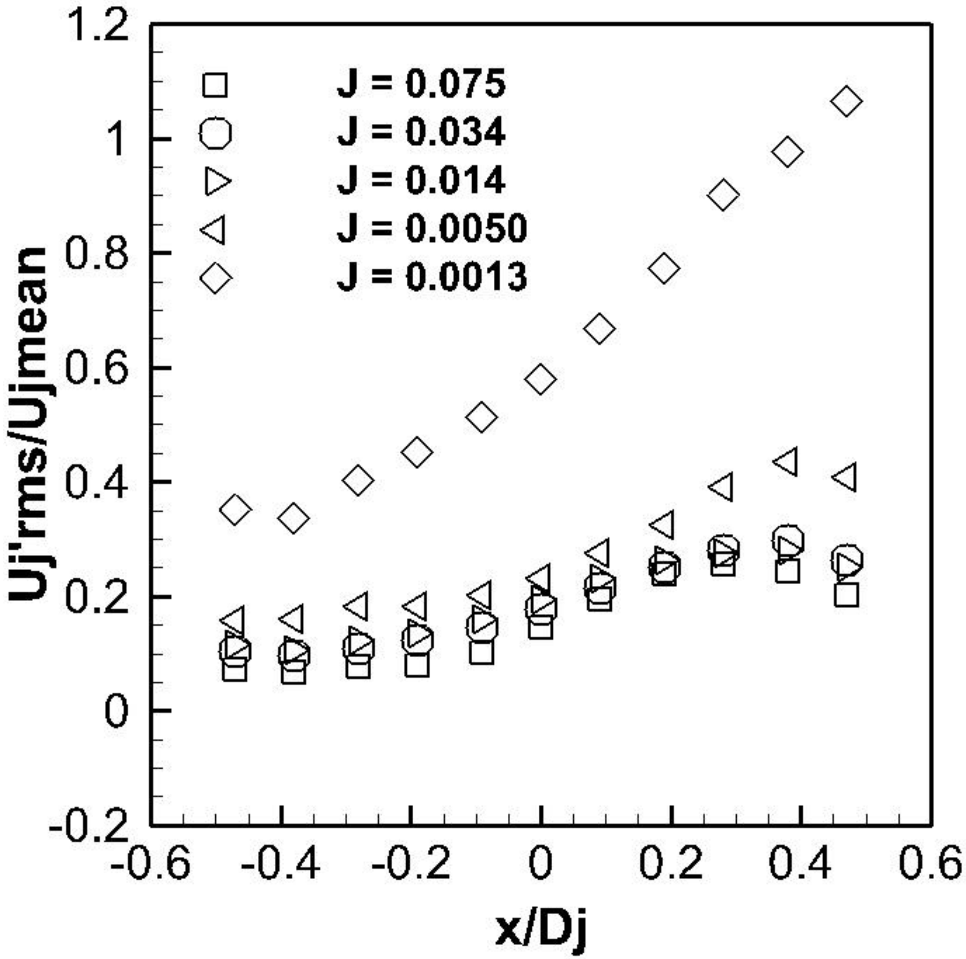




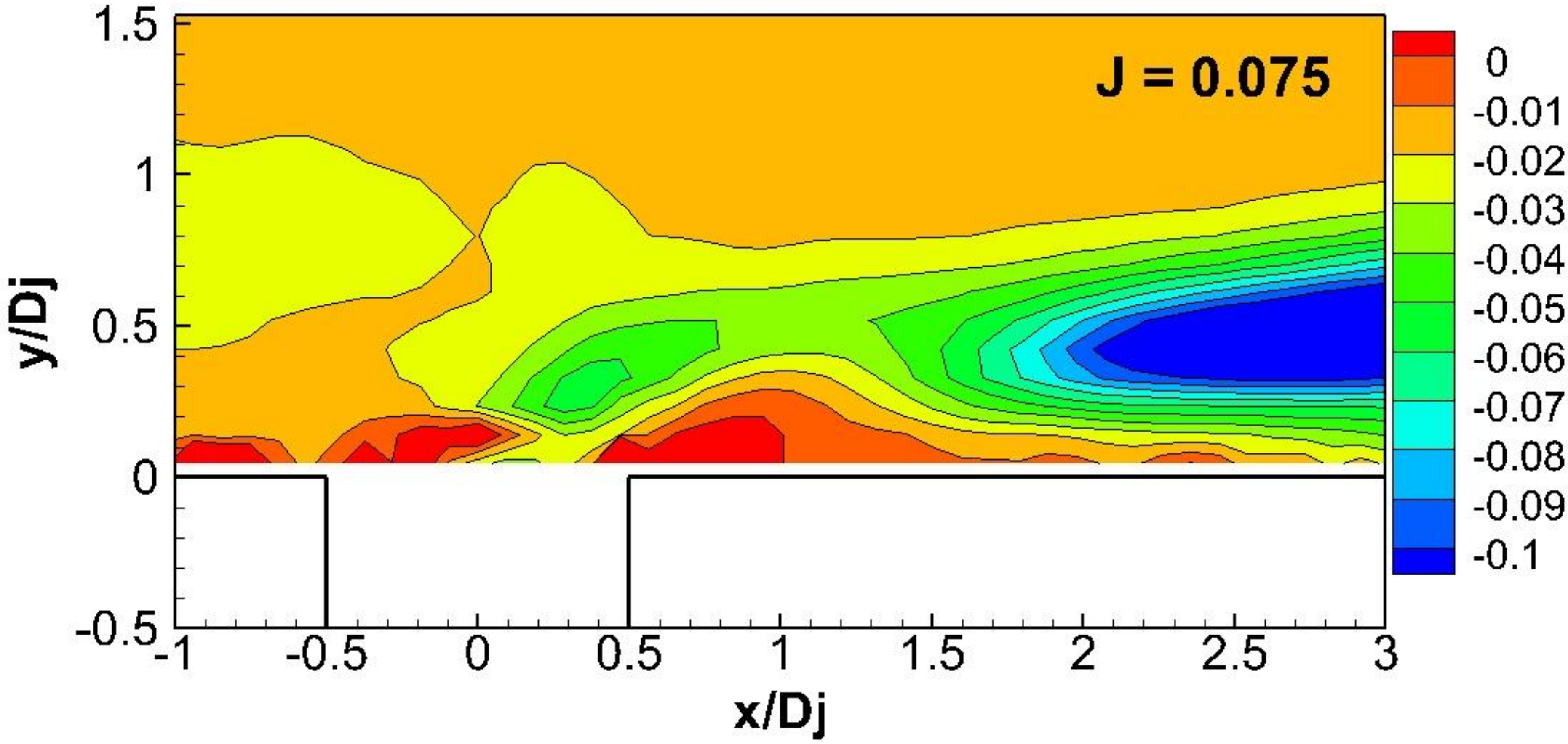
Jet Exit – Velocity Profile



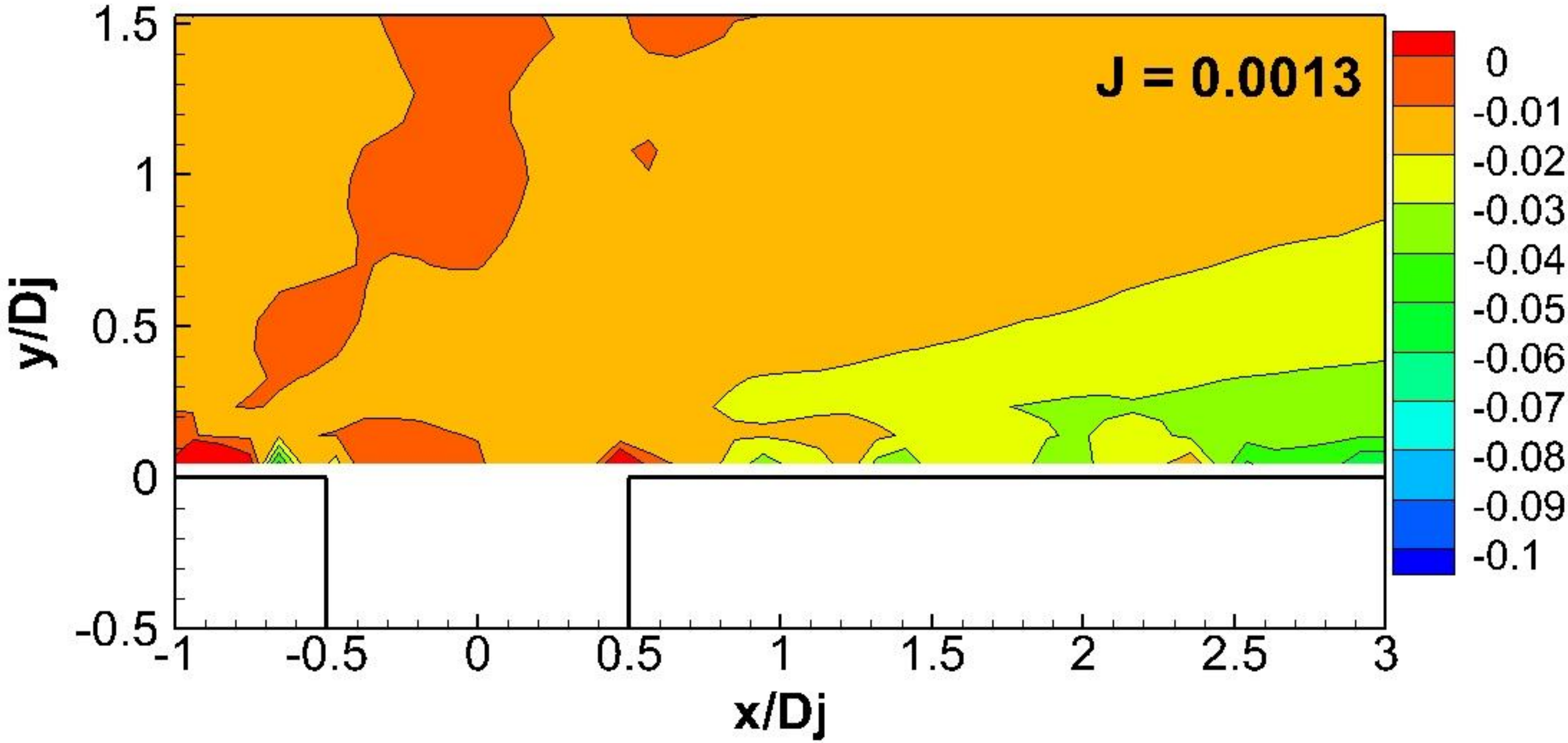
Jet Exit – RMS Profile



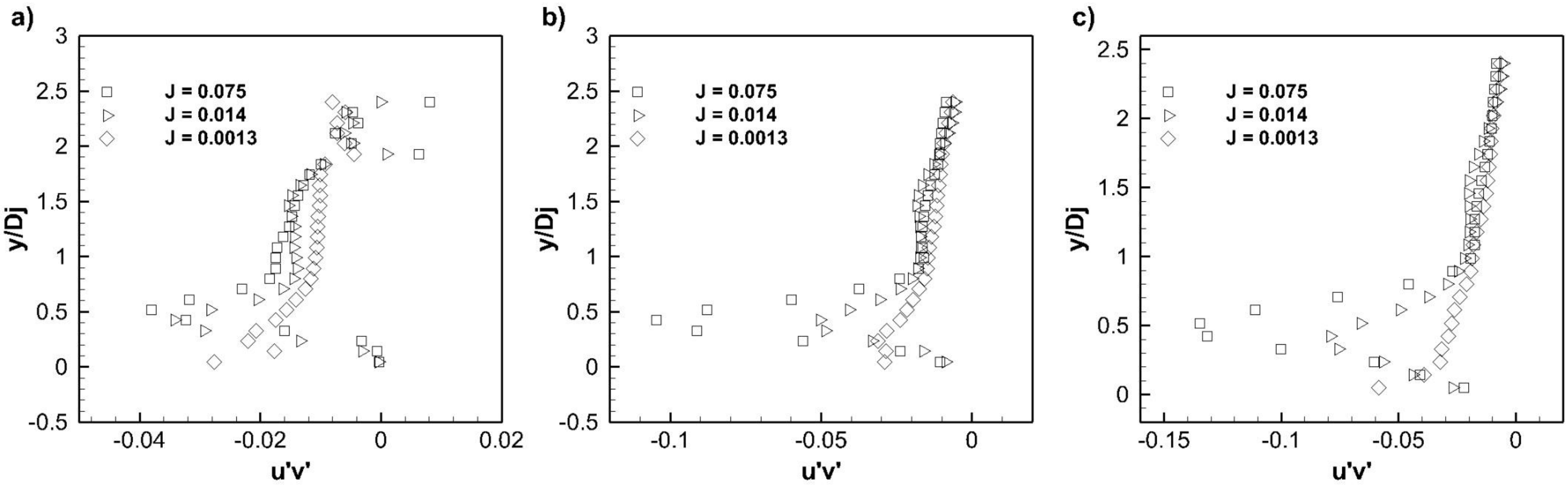
Reynolds Shear Stress, *u'v'*



Reynolds Shear Stress, *u'v'*



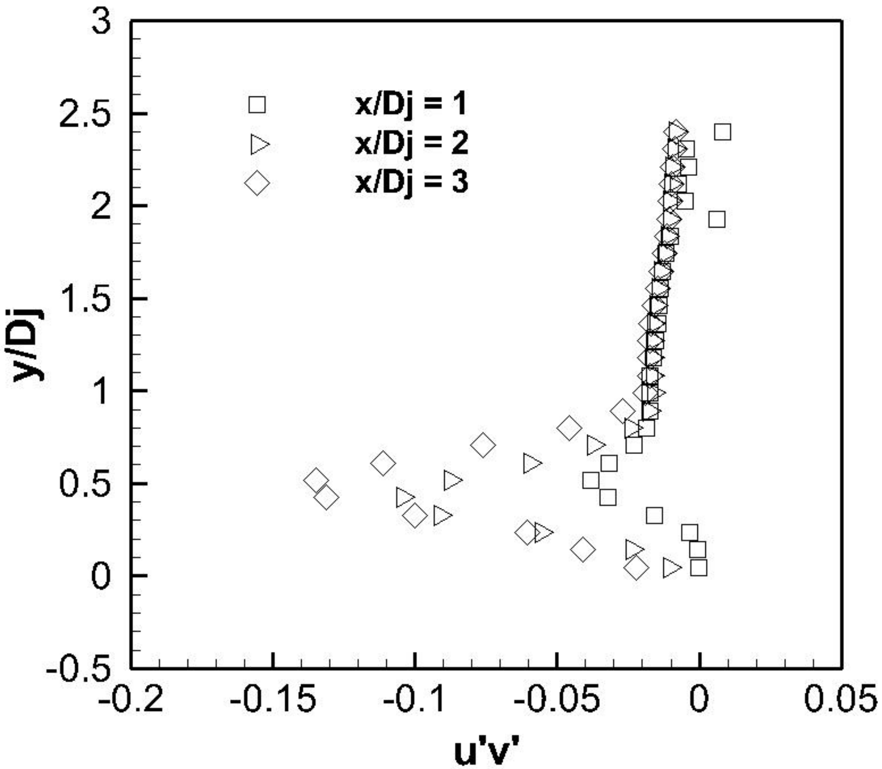
Reynolds Shear Stress, *u’v’*



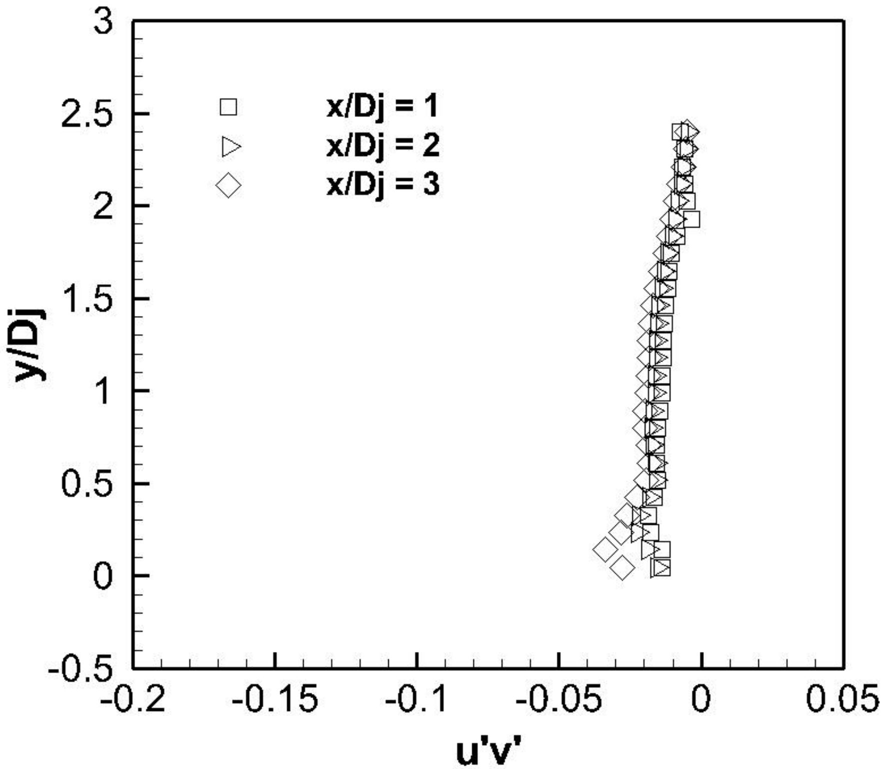
$x/D_j = 1$ $x/D_j = 2$ $x/D_j = 3$

Reynolds Shear Stress, *u'v'*

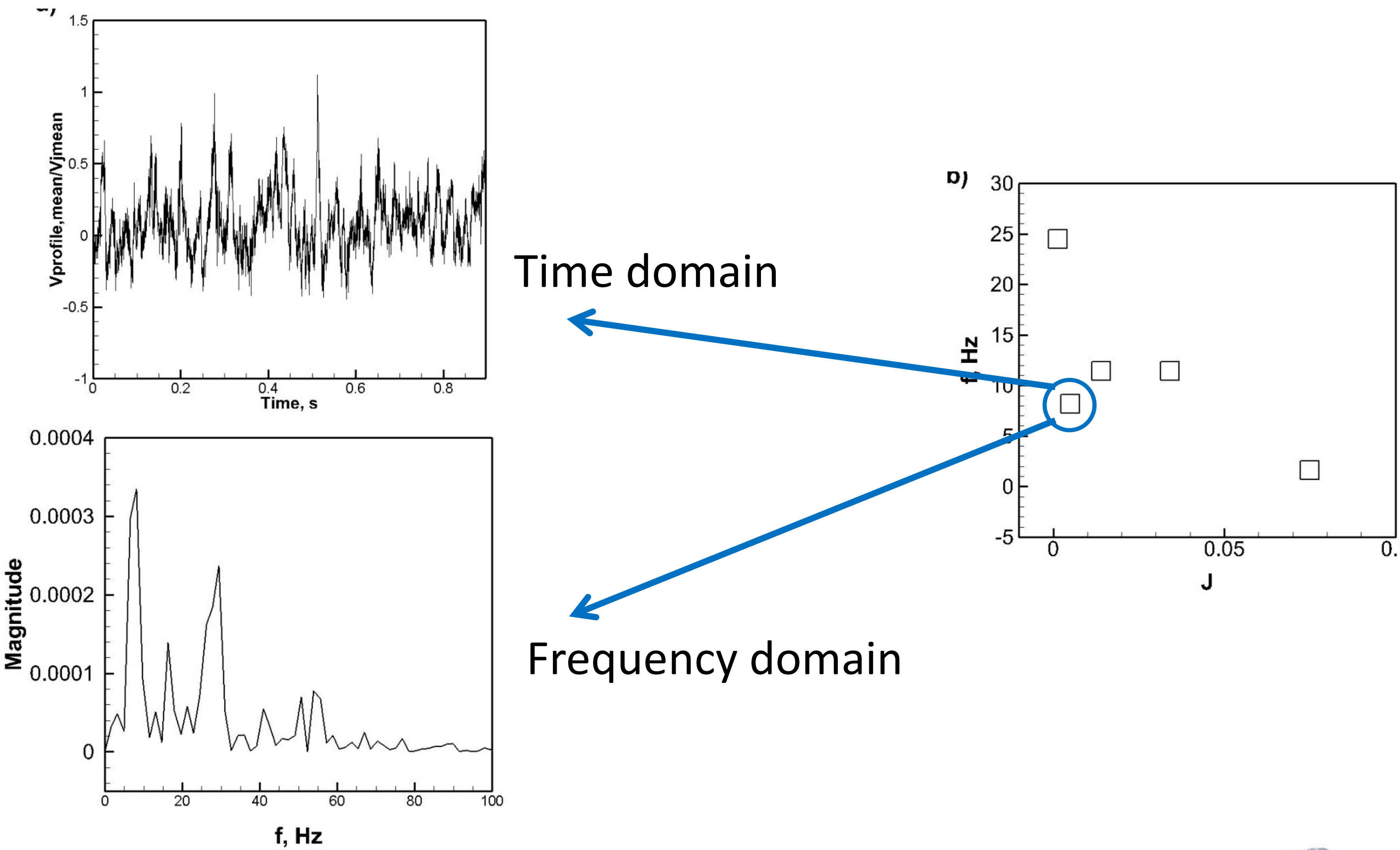
$J = 0.075$



$J = 0.0013$



Time Dependent Jet Behavior



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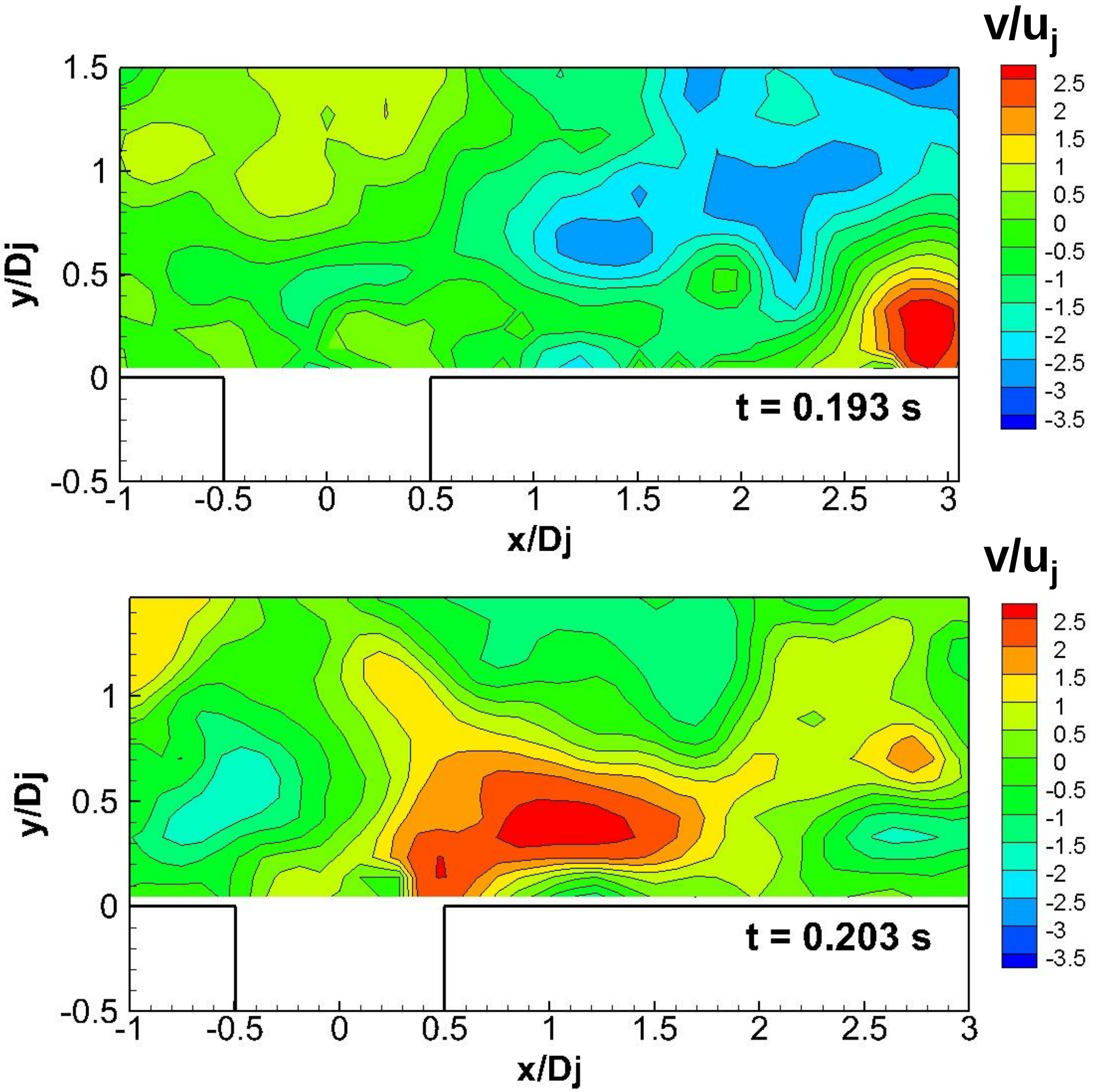
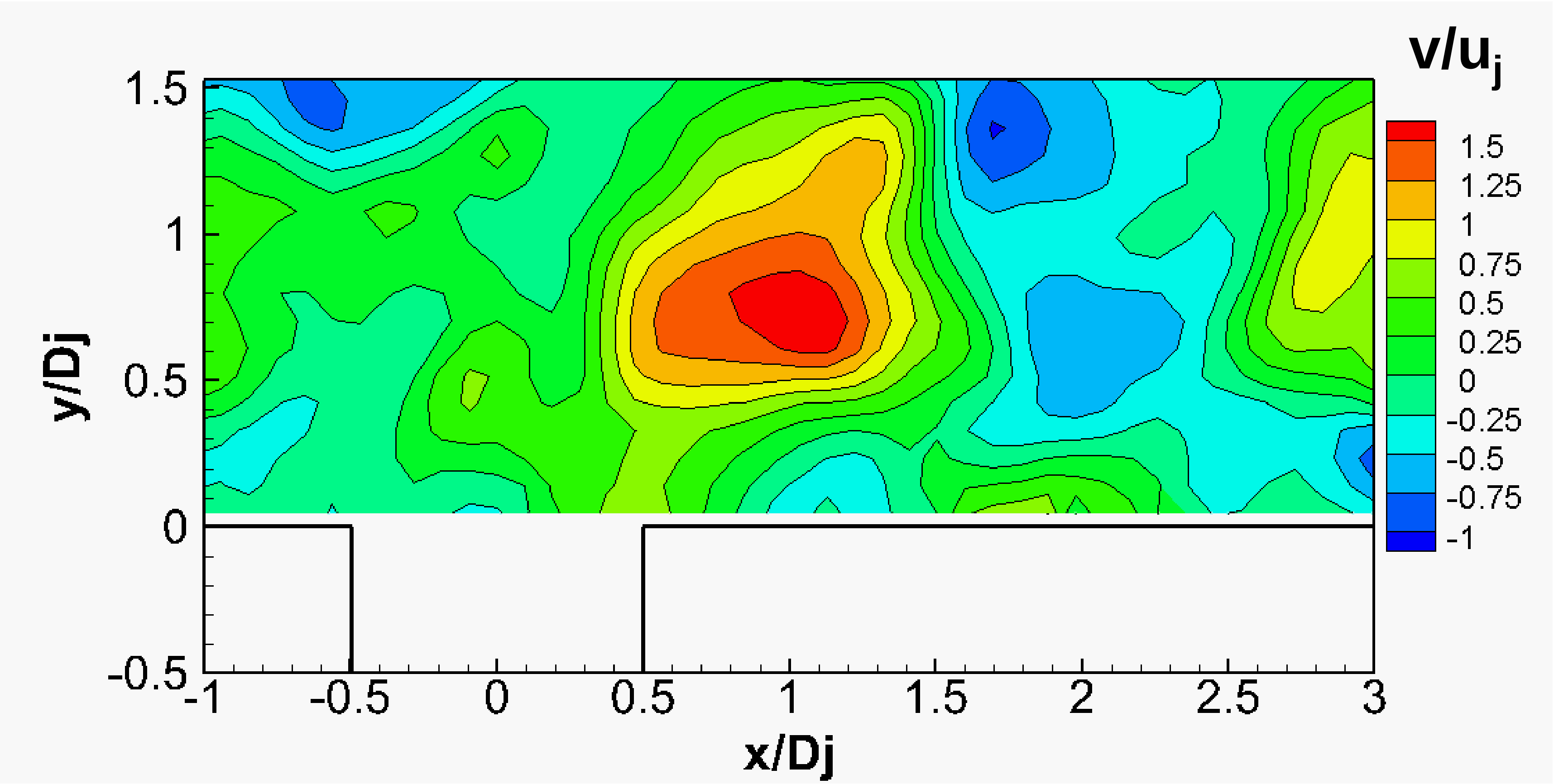


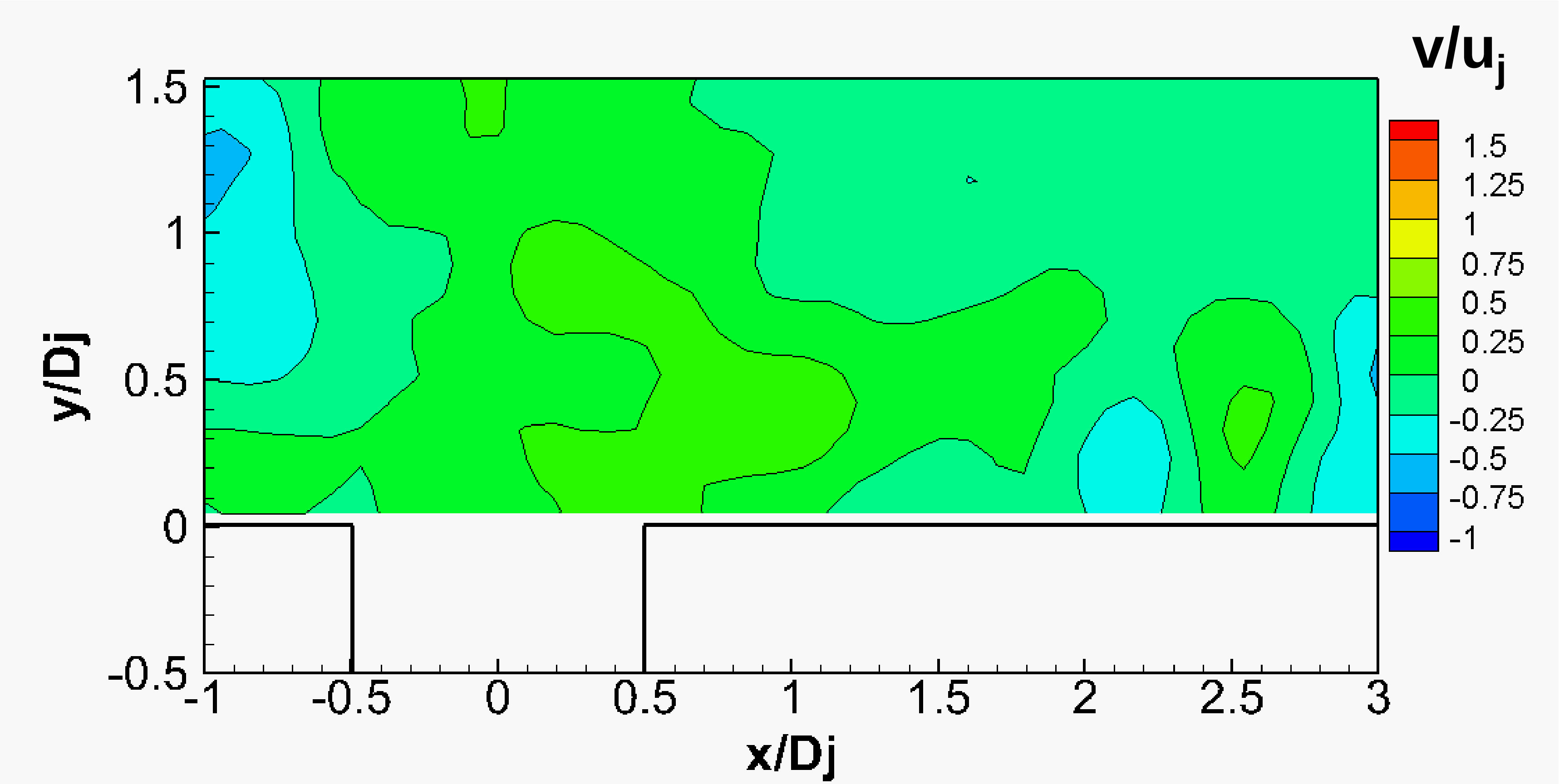
Time Resolved Jet Behavior

$J = 0.0050$

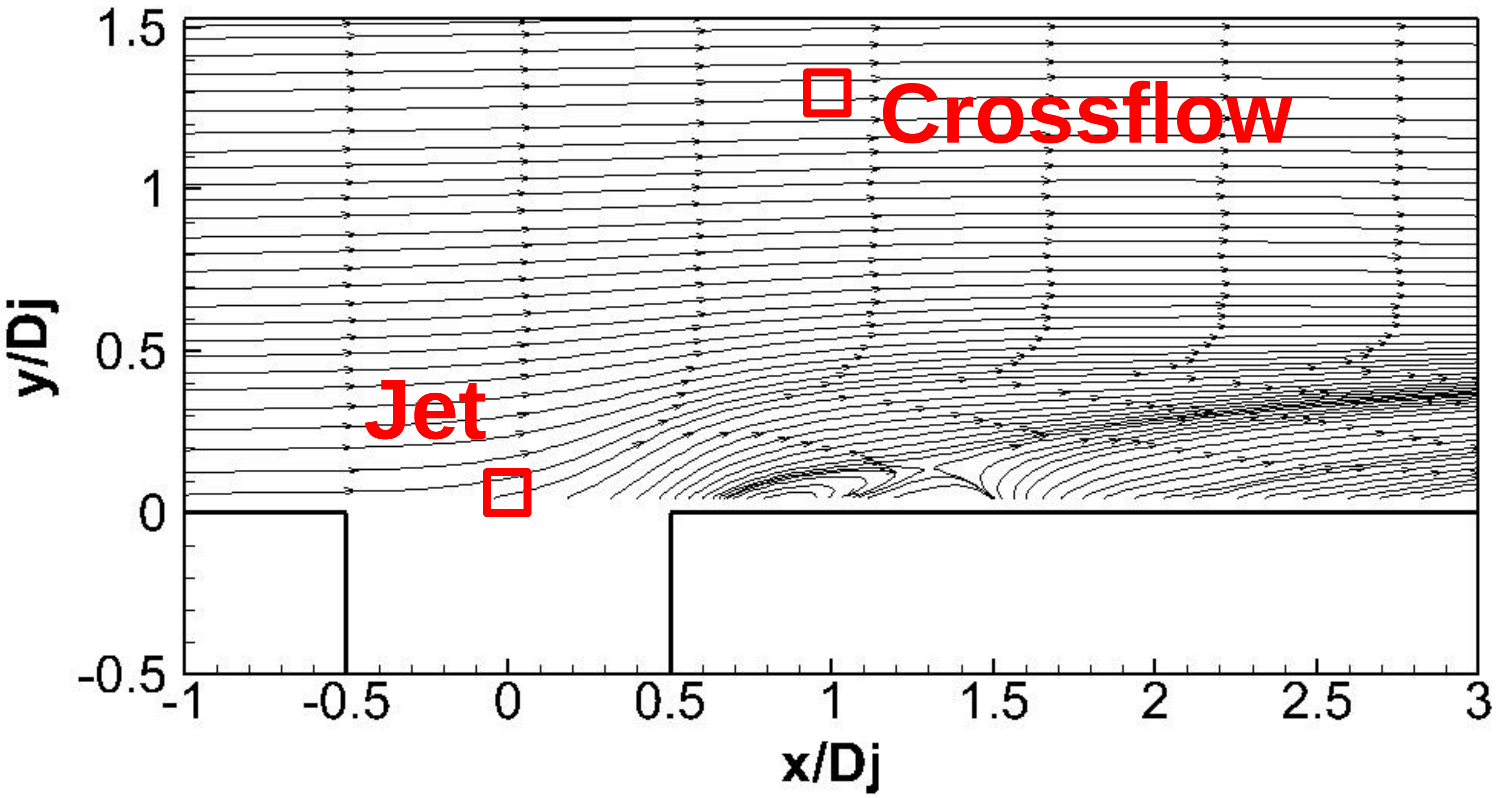


Time Resolved Jet Behavior

$J = 0.075$



PIV Precision Uncertainty



Precision Uncertainty – Jet

J	***u'²***	***v'²***	***u'v'***
0.075	0.0591	0.0045	0.0111
0.014	0.0655	0.0008	0.0068
0.0013	0.0844	0.0009	0.0064

$u_{prec} = 2S_i / N^{1/2}$

S_i = standard deviation of ith parameter

N = number of samples (3,000)

Conclusion

- **Confirmed jet and crossflow interaction for *M* = 0.275 (*J* = 0.075)**
- ***J* = 0.0013 minimizes crossflow penetration**
- ***J* = 0.0013 is most unstable value of those studied**
- **PIV data provides evidence for highly 3-dimensional jet and crossflow interaction**
- **Reduced Reynolds shear stress values indicate potential improved performance of low momentum jets for use in film cooling applications**
- **Ingestion of crossflow fluid creates pulse-like jet behavior**

Questions?

Backup

Precision Uncertainty – Jet

J	*u'*	*u'²*	$\sqrt{u'2}$	*v'*	*v'²*	$\sqrt{v'2}$	*u'v'*
0.075	0.0440	0.0591	0.0222	0.0084	0.0045	0.0057	0.0111
0.034	0.0532	0.0677	0.0235	0.0069	0.0019	0.0041	0.0095
0.014	0.0520	0.0655	0.0238	0.0048	0.0008	0.0028	0.0068
0.0050	0.0490	0.0714	0.0255	0.0033	0.0005	0.0021	0.0045
0.0013	0.0488	0.0844	0.0279	0.0042	0.0009	0.0027	0.0064

Precision Uncertainty - Crossflow

J	u'	u'^2	$\sqrt{u'2}$	v'	v'^2	$\sqrt{v'2}$	$u'v'$
0.075	0.0186	0.0577	0.0123	0.0103	0.0051	0.0067	0.0053
0.034	0.0224	0.0961	0.0170	0.0098	0.0045	0.0063	0.0043
0.014	0.0195	0.0542	0.0127	0.0090	0.0036	0.0057	0.0044
0.0050	0.0218	0.0975	0.0167	0.0093	0.0042	0.0060	0.0043
0.0013	0.0170	0.0415	0.0109	0.0090	0.0038	0.0057	0.0051

Experimental Conditions

- Particle Image Velocimetry (PIV) Parameters
  - 527 nm light source
  - 100 ns pulses
  - 0.5 mJ/pulse
  - Image-pair time separation = 120 μs
  - Image-pair capture rate = 3348 Hz
  - Particle diameter = 1 μm
  - 20 particle per 32 x 32 pixel interrogation region
- Crossflow
  - $Re_o = 14{,}000$
  - $u_o = 2.71$ m/s
- Jet
  - $62 < Re_j < 472$
  - $u_j = 0.731$ m/s